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Workshop on Communications in Fading Dispersive Medium 5,6 June 1979

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IEEE Communication Society

Naval Underwater Systems Center
Newport, Rhode Island • New London, Connecticut

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This document contains the abstracts of papers presented at the "Workshop on Communications in Fading Dispersive Medium" held on 5, 6 June 1979 at the Naval Underwater Systems Center, New London Laboratory, New London, Connecticut. It was jointly sponsored by the Naval Underwater Systems Center and the Communications System Discipline Committee of IEEE Communications Society.

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Foreword

This document contains the abstracts of papers presented at the *Workshop on Communications in Fading Dispersive Medium* held on 5, 6 June 1979 at the Naval Underwater Systems Center, New London Laboratory, New London, Connecticut. It was jointly sponsored by the Naval Underwater Systems Center and the Communications System Discipline Committee of IEEE Communications Society.

The purpose of this workshop was to bring together a small group of specialists and technical leaders for an exchange of information and to discuss new and controversial developments in the field of communication over fading dispersive media.

Approximatly 60 persons from government, industrial, and educational institutions attended this two day workshop. A total of 23 papers were presented during sessions which were very informal to permit a free exhange of ideas. Topics covered included sensors, experimental results, signal processing, signal design and coding, and characterization of fading dispersive medium.

Azizul H. Quazi
Technical Chairman
Naval Underwater Systems Center
New London Laboratory

Session 1

1.1

Laboratory Channel Simulation Tests of a Coded Tonal Frequency Diversity Long-Range Undersea Communications System

John N. Pierce
Signatron Inc.

William C. Knight
Raytheon Company

Diane M. Knight
Raytheon Company

This paper addresses some aspects of performance measurement of a communications system designed for an acoustic path that exhibits fading, frequency smear, and time delay dispersion. The emphasis is on the use of channel simulation in the laboratory as a tool to predict in-the-water performance. First outlined are the relevant channel characteristics as well as transmitter and receiver modulation demodulation. Then outlined are the reasons for the desirability of laboratory simulation as an economical augmentation of at-sea testing. The channel simulation technique that was used and some implementation *tricks* that permitted implementation using available computer hardware and software are described. A description is presented of specific tests used to validate and calibrate the simulator's fading statistics, Doppler smear, delay spread, and power level. Measurements of modem performance are described, including methods of extrapolating measurements to arrive at estimates of low-probability events. Finally, the results of channel simulation measurements are presented and compared with design predictions.

1.2

Retrospective Analysis of Sea Test Data of a Coded Tonal Frequency Diversity Long-Range Undersea Communications System

John N. Pierce
Signatron Inc.

William C Knight
Raytheon Company

Diane M. Knight
Raytheon Company

A technical evaluation was held in 1979 of a long-range undersea communications system described in the companion paper. Extensive laboratory channel simulation tests and limited use of the system malfunctions. While the major purpose of this sea test was to verify that the system was usable for its operational objectives, it also provided a valuable opportunity for quantitative comparison of laboratory and at-sea performance through real-time message reception and later laboratory analysis of tape recordings in both analog and digital form. The small number of signal transmissions available made even more important a thorough and well-conceived retrospective laboratory analysis. Signaling ranges and experimental geometries were chosen so that failure mechanisms could be observed by taking advantage of the additional available information during a structured sea test that is usually unavailable in operational use.

This paper describes methods conceived to examine why the system worked (when it worked) and why it did not work (when it did not work), through quantitative evaluation of several possible error mechanisms. The methods included comparison of expected signal-related channel statistics and noise statistics as well as available signal-to-noise ratios. The results of the analyses are a relatively complete understanding of system failure mechanisms, their related environmental causes, and operational guidelines that can avoid these failure mechanisms. The testing showed that the channel characteristics which were assumed in the design of the system were sufficiently close to those that actually exist, and that system similarities to these characteristics are logical and explainable.

1.3

The Arctic Channel: An Acoustic Waveguide

F. DiNapoli, D. Viccione
Naval Underwater
Systems Center
New London Laboratory

H. Kutschale
Lamont-Doherty
Geological Observatory
Columbia University

The Arctic Basin provides a unique channel for acoustic propagation. The two features peculiar to the polar environment that most strongly influence the transmission of underwater sound are the permanent ice cover and the uniform (constant gradient) velocity profile. As a result, the basin exhibits propagation characteristics analagous to an inhomogeneous acoustic wave guide. Only a few low order modes will propagate through it and the non-linear frequency dependent time delay of the channel may be accurately computed as a function of range. In the Arctic channel, the dispersion is such as to produce a "chirp" frequency modulation on a transmitted pulse. Consequently the channel itself may be used as the matched receiving filter by transmitting a time reversed ("chirp") waveform and letting the dispersion effect compress the waveform. This process will be strictly range dependent but the processing gain (compression ratio) appears to vary slowly over intervals of 50 kyds at ranges in excess of 200 kyds.

1.4

Adaptive Channel Modeling and Multipath Recombination for Broadband Underwater Acoustics Communications

E. H. Satorius, M. Juniper, G. Garcia and J. Zeidler
Naval Ocean Systems Center

Recently, a test bed has been developed at the Naval Ocean Systems Center for the purpose of studying adaptive reception of broadband messages via underwater acoustic communication channels. The progress which has been made toward the development of broadband underwater acoustic communication techniques will be summarized. Also, experimental results which illustrate the impulse response structure and stability of some underwater acoustic communication channels will be presented and discussed. Experimental data which illustrates the ability of an adaptive receiver structure based on the Widrow Hoff LMS adaptive algorithm to perform real time channel modeling and multipath recombination will be discussed.

1.5

Alert Signal Format for Reliable Medium Range Underwater Communications

Donald E. Jackson
Sperry Gyroscope

A reliable tactical underwater communication system must be designed for high probability of detection of the communication alert signal having unknown doppler shift while having a low false alarm rate in the presence of background noise variations, local shipping, sonar pings, own ship induced noise, and frequency occuring biological interference. This talk will describe the alert signal design and receiver unlock algorithms utilized by SAMAC in its MDR (medium data rate) implementation. Operation of the alert and unlock algorithms during actual sea trials will be discussed.

Session 2

2.1

Hybrid Ray-Mode Methods in Underwater Acoustics

L. B. Felsen
Polytechnic Institute of New York

High-frequency signal propagation in a ducting environment has traditionally been analyzed in terms of guided mode expansions (comprising discrete and, when appropriate, continuous mode spectra) or ray expansions. For tractability, these expansions are usually truncated with only a vague estimate of the truncation error. Moreover, there has been little insight into the relation between modal and ray techniques since the former represent a global, while the latter represent a local, view of the propagation process. Finally, it has not been clear how to generalize these methods to non-idealized environments having lateral as well as vertical non-uniformities.

To deal with the difficulties noted above, we have investigated hybrid formulations whereby the transmitted signal is expressed in terms of a judiciously chosen combination of modal fields, ray fields, and a remainder. The number of modes and rays included in this hybrid representation is far less than when only modes or only rays are considered. This facilitates numerical treatment of the problem. It also grants new physical insights since the formulation implies that propagation processes characterized by rays with many reflections can be treated collectively in terms of a few modes while processes characterized by many modes can be expressed succinctly in terms of a few rays. Moreover, the procedure seeks to minimize the contribution from the remainder, usually given in computable integral form, so that the entire signal can be expressed as a mixture of ray and modal fields chosen according to criteria with poignant physical interpretation. Thus, the hybrid formulation quantifies the truncation error of a mode series in terms of rays, or equivalently, the truncation error of a ray series in terms of modes, with inclusion of a remainder that often turns out to be negligible over broad ranges of the observation point location. Since the number of modes in a modal expansion can now be suitably restricted, the eigenvalue problem in a complicated ducting environment may often be reduced to a simpler form for the retained cluster of modes. This feature economizes on computer time and required computer capacity. The hybrid formulation also appears to be well suited for treatment of lateral inhomogeneities along the duct provided that these occur gradually over a length interval equal to the local wavelength of the signal spectrum. Finally, the ray-mode field representation provides a new approach to scattering from strong inhomogeneities since physical insights derived from scattering of either a modal field or a ray field can be exploited to advantage.

The hybrid formulation descibed above was first applied to the study of time-harmonic electromagnetic surface fields on a concave circular cylindrical conductor excited by a line source located on the boundary. The relevant modes here are of the whispering gallery type, and the complete field representation involves a finite (though possibly very large) number of discrete modes as well as a continuous spectrum. The analysis has so far been applied to oceanic surface ducts with monotonic transverse refractive index profile. Results are presented to show the effectiveness of the hybrid representation.

2.2

Modeling Distributed Channels

J. K. Breton
Naval Underwater Systems Center

The Field Feedback Theorem (FF-BT) has been shown theoretically to give an exact solution for scalar wave propagation in inhomogeneous time varying media which may have irregular time varying boundaries. These solutions lead to specific three-dimensional algorithms. Since the medium (whether ocean or atmosphere) is necessarily regarded as a communication channel, these propagation results apply to a wide variety of traditional subjects including telecommunication, detection, remote sensing, etc. In addition, it is well known that physical channels through which information is passed can be regarded as space time filters or general networks analogous to temporal filters or networks of conventional circuit and control theory. This approach presents quantitatively the beginning of an analogous theory for such distributed filter networks, specifically taking into account the physical (and distributed) nature of the channel.

2.3

Scattering Functions Measurement at Extremely Low Frequencies in the Arctic Basin

A. B. Baggeroer
Massachusetts Institute of Technology

In March and April 1978, in an experiment dubbed CANBARX, researchers of Bedford Institute of Oceanography, Lamont-Doherty Geological Observatory, Massachusetts Institute of Technology, and Woods Hole Oceanographic Institution measured several acoustic and seismic properties of the Arctic Ocean. An ice camp was established over the Canada Abyssal Plain consisting of an underwater acoustic array, various individual hydrophones, and an ocean bottom seismometer. Impulsive sound signals were created underwater with TNT charges.

CANBARX was unique in that the acoustic array provided a spatial display of various acoustic signals, and for the first time yielded azimuthal backscatter information on distant oceanic features. Scattering functions of the Arctic Basin at extremely low frequencies were measured as a function azimuth. These scattering functions were compared with the known bathymetry. Underwater features such as the Alpha and Lomonosov Ridges can be measured, and surprising *hot spots* near the McKenzie Cone can be seen, suggesting bottom roughness to a degree not appropriately represented on available charts.

2.4

Fourth Order Moments for a Surface Scatter Channel

John F. McDonald
Rensselaer Polytechnic Institute

Recent studies of the usual second order moments (e.g., range-Doppler plots) for surface scatter channels have shown that this channel is easily over spread in many circumstances of interest. Furthermore, detailed studies of range-Doppler plots for multiple reflected surface scattered rays for wide beam excitation have shown that readily exploitable structure suitable for signal design may be very adversely affected by this distortion. The cause for this difficulty is the extreme loss of signal shape integrity associated with the uncorrelated scatterer (US) behavior which results from even moderately wide excitation beams. This leaves only two alternatives for improving channel signaling rates beyond the rather simplistic value given by the inverse reverberation time of the channel. The first method consists of striving for very narrow beam excitation which results in a non-US type of channel characterization (e.g., interfrequency correlation functions). Here the signaling pulse time-spread is minimized. With shorter pulses, fading effects might be effectively handled by pulse interleaving and coding. The second method consists of exploiting some other feature of the scattered pulses such as a departure from Gaussian statistics. Such effects might be expected as a result of strong random phase modulation or distortion. Such departures are best studied with higher order moments. Other related studies of interest are signal design problems for non-US channels, nonlinear filters for non-Gaussian channels, and derivations of error bounds for coding in either of these limits of operation.

2.5

Comparison of a Phase Random Multipath Model to Ocean Acoustic Fluctuation Data

William R. Hamblen
Bolt Beranek and Newman Inc.

A phase random model is presented which predicts the form and dependence of probability densities for the amplitude rate and phase rate of an acoustic signal in the ocean in addition to the more commonly known densities for the signal amplitude and phase. The amplitude and phase densities are the well known Rayleigh and uniform densities. The amplitude rate and phase rate densities are shown to be Gaussian and a unique bell-shaped density,respectively. Under the assumptions of the model, the densities are shown to depend on two parameters only. The first parameter is a measure of power of the received signal, and the second parameter is defined as the single-path mean-square-phase rate and is a measure of the doppler spread of the channel. Comparison of the amplitude rate and phase rate densities with ocean acoustic fluctuation data is presented for the first time. Data obtained by the Woods Hole Oceanographic Institution are analyzed and compared with the predicted densities. For experiments conducted at 220 and 406 Hz over a 250 km range near Eluethera, values of the second parameter on the order of 10^{-3} sec^{-2} result. The agreement between the data and the predicted densities is excellent. (Work supported by ONR).

2.6

Medium Range Low-Frequency Signal Fluctuations

A. W. Novick
Mission Sciences Corp.

R. A. Shade
Hazeltine Corp.

Propagation fluctuations have been observed at low acoustic frequencies which vary at rates that far exceed those predicted by simple Lloyd mirror effects. A detailed analysis has been performed for representative deep water sites and the probable cause identified -- multipath interaction between the principal propagation mode and the modes just below it in energy. The theoretical fluctuation distribution is well fit by a Rician curve and is in agreement with measured data. This result is significant in that it implies that: (1) some measured *temporal* fluctuations reported may be related to platform motion, and (2) spatial fluctuations can be controlled through array design, possibly resulting in improved signal detection statistics.

Session 3

3.1

An Overview of Communication Over Fading Dispersive Media

S. Stein
SCPE, Inc.

A review is presented of the characteristics of typical radio and acoustic channels used for communications, where multipath fading is a major consideration. The broad principles employed to design systems for operating over such channels are outlined, and specific examples of current developments are identified.

3.2

The Parametric Source for Underwater Communications

W. L. Konrad
Naval Underwater Systems Center
New London Laboratory

The narrow beamwidth and lack of significant sidelobes of the parametric difference frequency source serve to minimize multipath and hence fading in underwater acoustic propagation. The implementation of parametric sources are described along with the characteristics of several sources suitable for communication. Finally, the results of several sea tests, one transmitting slow scan television, are reported.

3.3

Experimental Results of High Data Rate Underwater Communication Using Parametric Sonar

A. H. Quazi
Naval Underwater Systems Center
New London Laboratory

The Naval Underwater Systems Center, jointly with Sperry Research Corporation, conducted two experiments: one in fresh water and the other in deep ocean water to investigate the feasibility of high rate underwater acoustic communication using parametric sonar; and to determine the upper bounds on data rate for undersea communication channel.

A number of phase-shift-keyed frequency hopped signal formats were transmitted where data rate varied from 273 to 6600 bits per second over a range of 4 km. A band of 8800 Hz was used for all formats.

The receptions were recorded on a tape and later processed in the laboratory. The communication performance is presented in terms of signal to noise ratio and probability of error. It has been observed in the data analysis that underwater channels provide sufficient coherence to reliable communication (Eb/N_o = 30 dB and Pe = 10^{-3}) on limited range. Multiple differential phase modulated signals were demodulated correctly in excess of kilobits per second for both fresh water and ocean water tests.

3.4

Hydroacoustic Transducers

John V. Bouyoucos and Roger L. Selsam
Hydroacoustics Inc.

Hydroacoustic transducers for generating acoustic signals underwater from hydraulic power are described. The acoustic transmission produced by such transducers is a high power replica of a low level electric control signal input. The versatility of the power conversion process enables certain useful tradeoffs to be obtained between bandwidth, source level and power conversion efficiency. These tradeoffs are outlined. An example of the design process will be given in some detail along with the performance characteristics of a practical device. (Work supported in part by the Office of Naval Research and the Naval Electronic Systems Command.)

3.5

Hybrid Signal Processing for the Underwater Acoustic Channel

Dr. J. P. Costas
General Electric Co.

The non-stationary, time-varying multipath encountered in underwater channels is considered relative to active sonar and communications system design. Practical, workable solutions to this problem require both special signal waveform selections and hybrid signal processing techniques. Precise designs are neither possible or necessary. Hybrid systems of the type developed display very high performance levels and also exhibit a welcome tolerance to medium spread parameter mismatch.

A brief case history of active sonar system redesign and some typical sea test results are shown relative to the NUSC/GE MEDIOR program. These proven active sonar procedures were modified and applied to a General Electric internally-funded acoustic communications system known as MATCOM. This technique combines a unique time-frequency multiplexed *carrier* with special data keying methods. The resulting system uses normal signaling energy for both acquisition and on-line doppler and time tracking (no *pilot* signals used). Multipath structure is continually measured and updated so that diversity is realized from multiple arrivals. The technique is similar to the classical Lincoln Laboratories HF *RAKE* system. The ability of MATCOM to operate well below the noise level in the signal passband makes a signal presence verification by a third party difficult even when using fairly sophisticated spectral and analysis and display gear. The basic system architecture needed to provide these operational features will be discussed and tapes demonstrating the transmission security features of MATCOM will be played.

3.6

A Signal Design Approach for Fading Channels with Unknown Doppler

Richard R. Kurth and Robert Price
Sperry Research Center

A technique is described for designing M-ary FSK formats for diversity signaling over a fading channel which exhibits a significant, unknown Doppler shift. Its objective is the synthesis of bandwidth-efficient formats (i.e., message to tone frequency mappings) that can be successfully demodulated within specified limits of Doppler uncertainty at the receiver and which yield an estimate of the Doppler as a by-product.

The design of such Doppler resistant formats is posed as a problem in the contruction of one or more finite sequences of integers whose differences obey certain properties. As such it belongs to a class of *ruler problems* in additive number theory which have been . studied for a variety of applications: minimum redundancy of thinned antenna arrays, x-ray diffraction crystallography, self-orthogonal codes, and others. (For a partial review see Bloom and Golomb, "Applications of Numbered Undirected Graphs," *Proc. IEEE*, April 1977.) An approach to the design of diversity FSK formats with low message-Doppler ambiguity is described which draws upon results from this bodyof theory.

Session 4

4.1

High Speed Modem Techniques for Fading Dispersive Channels

F. M. Hsu, A. A. Giordano,
H. E. de Pedro and J. G. Proakis
GTE Sylvania

High speed communication systems for fading dispersive links are constrained by non-ideal channel characteristics such as bandwidth restrictions, signal fading, and multipath dispersion. Two major design issues include the modulation type and the adaptive receiver techniques that can be used. In this paper, we investigate bandwidth efficient modulation techniques, i.e., MPSK, PAM, PAMSK, and adaptive receivers for fading dispersive channels. The results indicate that a decision feedback equalizer with Kalman estimation of the tap coefficients achieves excellent tracking and error rate performance.

4.2

On the Application of Lattice Algorithms to Data Equalization

E. H. Satorius and J. D. Pack
Naval Ocean Systems Center

In certain Naval communication systems which employ high data rates (≥2 kbps), methods for data equalization are of interest. Typically, tapped delay line filters are used in data equalization applications. Recently, however, the use of lattice filters in equalization problems has been suggested. It is the purpose of this paper to examine some of the different lattice filters (including the least squares lattice structures) which have been proposed for equalization applications. Simulation results will also be presented and discussed.

4.3

Digital Simulation of Communication Systems Operating on Fading-Dispersive Channels

J. W. Modestino, K. R. Matis,
K. Y. Jung and A. Y. Ningo
Rensselaer Polytechnic Institute

A hardware/software system is described for the digital simulation of arbitrary point-to-point communication systems operating in fading-dispersive channel environnments. This system makes extensive use of interactive computergraphics and includes a PDP-1140 acting as host to a fast peripheral array processor. The user can configure a wide vareity of communication systems from basic modules provided as system facilities. These facilities include: source coders/decoders, channel decoders with a variety of soft-decision decoding options, modulators demodulators appropriate for a number of modulation strategies, extensive narrowband filtering options, and a basic decision feedback equalizer capability. The simulated channel represents a three-component multipath model consisting of a direct path, a specular multipath component, and a diffuse multipath component. In addition to additive white Gaussian noise (AWGN), the simulator includes the ability to model fairly general additive impulsive noise environments. The communications simulator is being employed both to evaluate existing modem performance and to explore new modulation/coding concepts appropriate for military communications. The design and operation of this system will be described and illustrated through typical graphical output.

4.4

A Closed Form Solution for Determining the Magnetic Field Strength Beneath a Loop Antenna Located at the Earth's Surface

Gene E. Layman
Science Advisor
U. S. Navy THIRD Fleet

The method for analyzing the electromagnetic fields produced by a radiating dipole located above the earth's surface was first formulated by Sommerfeld.* Several investigators have used the Sommerfeld integral equations in evaluating effects of dissimilar half-spaces and stratified media on electromagnetic, electrooptic, and acoustic fields. These integral equations, for which no known closed form solutions exist, have been solved for special cases (e.g., far fields) by using approximations of the integrand. While extremely useful for evaluating the far field strength of antennas radiating above a conductive medium (ocean or earth) the solutions are not applicable for evaluating near field effects that must be considered when determining field strengths at the limited communication ranges that are possible within the conductive medium.

This paper reports closed form solutions for magnetic field strength within the conductive medium produced by a radiating loop at the surface. An approximation, which the author has discovered, allows the field strength to be solved for all points located directly below the antenna. A definite integral equation of the form;

$$\int_0^\infty J_o(\rho u)\left[e^{-(u^2+\gamma_1^2)^{1/2}|z_o - z|}\right.$$

$$\left. + \frac{\gamma_o^2(u^2+\gamma_1^2)^{1/2} - \gamma_1^2(u^2+\gamma_o^2)^{1/2}}{\gamma_o^2(u^2+\gamma_1^2)^{1/2} + \gamma_1^2(u^2+\gamma_1^2)^{1/2}} e^{(u^2+\gamma_1^2)^{1/2}(z+z_o)}\right]$$

$$\times \frac{u}{(u^2+\gamma_1^2)^{1/2}}\,du$$

is shown to be solvable by adapting valid approximations discussed in the paper.

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* Sommerfeld, A., "Uber die Ausbreitung der Wellen in der Draktlosen Telegraphie", *Ann. Physik*, Vol. 28, p. 665, 1909.

For the case $\rho = 0, z_o = 0$, the solution to the integral is approximated to be

$$1 - \frac{\gamma_0^2}{\gamma_1} K_1(-\gamma_1 z) + \frac{\gamma_0^2}{\gamma_1^2} e^{\gamma_1 z} \qquad z < 0$$

where K_1 is the modified Bessel function, and γ_o, γ_1 are parameters of the medium.

Use of this approximation method produces a closed form expression of field strength that is valid in both near and far fields. This important solution can be used in determining the field strength at depths for such applications as communication between surface and submerged or underground locations.

4.5

Review of EM-Wave Scattering in Radio Communications

A. Nejat Ince
The Western Union Telegraph Co

Communication systems which rely on EM-Wave propagation through fading dispersive media are:

1. HF
2. Ionoscatter
3. Meteor-burst
4. Field-Aligned Scatter
5. Troposcatter
6. Chaff and Needles
7. Optical Scattering by Aerosols.

This presentation focuses on and discusses modeling, prediction and signal processing as related to systems (1) (3), and (5) above. These systems provide the range and capacity required for most applications more economically and conveniently than the other systems. The main points of the presentation may be summarized as follows:

• Performance predictions for troposcatter systems can be made but with an accuracy which does not exceed 10dB. It appears that the predictions of the path-loss statistics may be improved by taking into account more details of the meteorological conditions. There is also the need for collecting data on climatic effects for regions where this data does not exist.

• A factor contributing to the large differences between different prediction methods in estimating the performance of a tropscatter link and also to the difference between predicted and measured result, is the so-called aperture-to-medium coupling loss. Uncertainties exist in the definition, measurement and scatter mechanisms involved in this loss factor. It is quite clear that the aperture-to-medium coupling loss of an antenna is dependent on the gains of the two antennas used in transmission and also on the separation of the two antennas. On the latter issue, widely differing results are given in the literature although for the ranges of most practical interest (200-300 kms) all predictions converge to within a few decibels providing that the free-space gain of the antennas are less than 40 to 50 dB. It should be pointed out here that even though the coupling loss increases with antenna gain, the increase in antenna size might still be desirable because multipath delay spread decreases with increasing antenna size.

• Digitalization of tropospheric scatter links requires the use of adaptive modems and bandwidths larger than those needed by equivalent analog systems. Several adaptive modem techniques are available. Prototype adaptive modems exist today which allow the transmission of up to about 10 Mega bits per sec over typical troposcatter paths. It is evident that more R&D work needs to be undertaken to develop modems which are capable of coping with the maximum expected delay spreads on operational links (including aircraft echoes) and of providing the maximum possible economy in frequency usage. Further studies using multi-level coding and angle diversity are indicated. Power control techniques will also help to reduce interference thus permitting more efficient use to be made of the frequency spectrum.

• Physical laboratory modeling techniques seem to lend themselves to studies of radio wave propagation in the troposphere. By creating an inhomogeneous gaseous medium (or liquid suspension) through which is propagated a coherent light beam, investigations can be carried out conveniently and economically into the problems outlined above and into the determination of the significance of the common volume and beambending in relation to the scatter loss and multipath delay spread. Even though it would be impractical to model exactly the atmospheric inhomogeneities in the scattering fluid, it is believed that useful information could well be derived from such a modeling technique

• Less obvious, but surely with a certain future in special applications, is the use of meteor burst communications. Regardless of its intermittent nature it allows the transmission of instantaneous data rates of up to hundreds of kilobit per sec. Here again there is a need for a more world-wide knowledge of the scatter mechanism; in this case a knowledge of the distribution of the radiants of meteors.

• The use of adaptive equalizer techniques for HF paths seems problematic and uncertain. It appears that the use of the spread-spectrum technique may be a better approach for coping with the multipath problem at HF. This would also have the advantage that the effect of interference and noise of an impulsive nature would be reduced.

• For optimum modem design and comparative evaluation of implemented modums use should be made of path simulators. Different types (software, hardware, synthetic and playback channel simulators) of simulators can be implemented and used to fulfill different requirements.

• In planning and implementing communciation systems the transmission standards to be adopted should be specified taking into account the characteristics of the terminal devices as well as the application for which they are used, the requirements for monitoring and measuring the implemented system, and the network (dedicated and switched) into which it is to be incorporated. It should be borne in mind also that, even though one may wish to specify not only the average channel behavior but also the statistical distribution of the impairment, the parameters available to the equipment and system designer may not permit the noise error patterns to be controlled completely, particularly when an existing system is being converted from analog to digital working.